PHYTOPLANKTON STUDIES IN THE BAY OF QUINTE

II-relationships between seston-phosphorus, nitrogen, carbon and phytoplankton

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Correction - Figure 1 - Title on page 7

Graph on page 8

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PHYTOPLANKTON STUDIES IN THE BAY OF QUINTE: II - RELATIONSHIPS BETWEEN SESTON-PHOSPHORUS, NITROGEN, CARBON AND PHYTOPLANKTON

by

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ABSTRACT

Characterization of seston samples from the trophogenic waters of the Bay of Quinte, 1967, 1968, were carried out with respect to three nitrogen fractions, three phosphorus fractions, organic carbon, algal volume and chlorophyll a.

Significant direct positive relationships were found to exist between each of the various parameters and ratios (wt:wt or wt:cm^3) were calculated with the following ranges obtained: phosphorus - labile:nonlabile - 1.5 - 4.0:1 (g:g); nitrogen - labile:nonlabile - 1.1 - 3.0:1 (g:g); carbon:nitrogen - 7.0 - 22.0:1 (g:g); carbon:phosphorus - 95.7 - 386.2:1 (g:g); nitrogen:phosphorus - 4.4 - 55.2:1 (g:g); carbon:algae - 0.14:1 (g:cm^3); nitrogen:algae - 0.0066 - 0.0206:1 (g:cm^3); phosphorus:algae - 0.0004 - 0.0015:1 (g:cm^3); carbon: chlorophyll a - 0.10:1 (g:mg); nitrogen:chlorophyll a - 0.0058 - 0.0172:1 (g:mg); phosphorus:chlorophyll a - 0.0003 - 0.0012:1 (g:mg).

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INTRODUCTION

Nutrient ratios of seston from natural aquatic systems have been employed to evaluate the availability of such nutrients as phosphorus and nitrogen for phytoplankton development (Strickland, 1960; Lewin, 1962; Mackenthun, 1965; Hutchinson, 1967; Vollenweider, 1969). The results of various extractive techniques employed to identify the phosphorus fractions of plant cells suggest that phosphorus may be accumulated by algae in excess of their immediate requirements (summarized by Vollenweider, 1970). Seston nutrient contents may therefore be somewhat misleading for estimating the critical nutrient requirements of associated algae.

Fitzgerald and Nelson (1966) have described a technique to determine the essential phosphorus content of algae which may have some application to the aquatic environment. This procedure, slightly modified, has been employed in the following study to examine interrelationships between the phosphorus, nitrogen, carbon, and phytoplankton associated with the seston of samples obtained during a previously described limnological assessment of the Bay of Quinte (Christie, 1972).

MATERIALS AND METHODS

The suspended solids or seston which were analyzed in this study are identical with the materials previously employed to characterize the standing crops of phytoplankton present in the trophogenic waters at three locations in the Bay of Quinte - Big Bay (B), Glenora (G), Conway (C) - during 1967, 1968.

Initial concentration of this material, previously described by Christie (1972), involved either treatment of the original raw water sample with mercuric chloride followed by filtration in a Sedgwick-Rafter sand filter funnel, 1967, or sedimentation following treatment of the raw water with Lugol's solution, 1968. Raw water volumes of 1000 ml or 500 ml were concentrated to a final volume of 25 ml. Chemical analyses were carried out using 2.5 ml aliquots of the final concentrates.

Three phosphorus and nitrogen fractions and one organic carbon fraction were measured. The procedures employed to obtain these different fractions are as follows:

Fraction 1: P_1, N_1 - aliquots of original concentrate were placed in 125 ml Erlenmeyer flask and digested

C_p - aliquots of original concentrate were injected into a carbon analyzer.

Fraction 2: P_2, N_2
- centrifuge aliquot 5 minutes at 10,000 G
- remove supernatant by gentle siphoning
- add 5 ml glass distilled water, agitate
- centrifuge 5 minutes at 10,000 G
- remove supernatant by gentle siphoning
- repeat two more times
- rinse final pellet into an acid-washed 125 ml Erlenmeyer flask with three 5 ml washes of glass distilled water, agitating between rinses.

Fraction 3: P_3, N_3
- centrifuge aliquot for 5 minutes at 10,000 G
- remove supernatant by gentle siphoning
- add 5 ml of N, P free salt solution (Fitzgerald & Nelson, 1966), agitate
- place tubes in boiling water bath for 1 hour
- after cooling, centrifuge 5 minutes at 10,000 G, remove supernatant by gentle siphoning

- rinse pellet with 5 ml of salt solution, agitate
- centrifuge for 5 minutes at 10,000 G
- siphon off supernatant
- repeat rinsing, centrifugation and siphoning two more times
- rinse final pellet into 125 ml Erlenmeyer flask with three 5 ml aliquots of glass distilled water, agitating between rinses.

All glassware was acid washed before use. Centrifugation was carried out using 10 ml conical tubes and a Sorvall SS-1 centrifuge. Carbon analyses were measured using a Beckman 91 Model 915 Carbon Analyzer.

The contents of flasks containing aliquots for nitrogen and phosphorus analyses were digested with sulphuric acid and potassium persulfate. After conversion of the organic nitrogen to ammonia, and total phosphorus to ortho phosphorus, the quantities of nitrogen and phosphorus were measured on a suitably adapted Technicon Auto-Analyzer, the former based on the reaction between ammonia and alkaline phenol hypochlorite, and the latter using the phosphomolybdate colourimetric method (Brydges, 1970).

Before the above analyses were undertaken, preliminary experiments were carried out to compare the two

methods of preservation and concentration with respect to the nitrogen and phosphorus contents of the suspended solids. Materials for these trials were obtained from an in vitro 10 litre culture of Oscillatoria spp. growing in Bristol's medium (Starr, 1964). Preservation and concentration was carried out using 500 ml aliquots of the culture, phytoplankton density about 0.1 $cm^3.m^{-3}$. by treating one aliquot with 12.5 ml 0.7 $g.L^{-1}$ $HgCl_2$ followed by sand filtration, or by adding 10 drops of Lugol's solution and concentrating by sedimentation. Final concentrates in each case had a volume of 25 ml of which 2.5 ml aliquots were used in replicated analyses.

Statistical analyses of the data from these trials indicated no difference between the two methods of preservation and concentration with respect to the phosphorus and nitrogen contents of the suspended solids.

Statistical analyses of data accumulated in this study were carried out following procedures outlined in Snedecor and Cochran (1957).

RESULTS

Seston Nutrients and Aqueous Fertility

The quantities of phosphorus (P_1), nitrogen (N_1), and carbon (C_p) present in the seston of water samples obtained from the trophogenic waters of the Bay of Quinte.

at three locations - Big Bay (B), Glenora (G), Conway (C), during the periods April to October, 1967 and April to July, 1968 and associated concentrations of total phosphorus (P_t), organic nitrogen (N_o), inorganic nitrogen (N_i), total inorganic carbon (C_t) and estimated carbon dioxide as carbon (C_i) are illustrated in Figure 1.

These data have been summarized in Table I. Also included are the mean and range of the quantities of phytoplankton either in parts per million by volume (cm^3) or as chlorophyll a (mg) and the phosphorus and nitrogen content of seston samples after centrifugation and rinsing (P_2, N_2), or a boiling water treatment (P_3, N_3).

The phosphorus (P_1), nitrogen (N_1) and carbon (C_p) content of the seston in relation to the total phosphorus (P_t), organic nitrogen (N_o) and inorganic nitrogen (N_i), and the inorganic carbon (C_t, C_i) was examined by carrying out regression analyses (Table II). Only data from samples collected in Big Bay and Glenora, 1967, indicate the existence of a positive direct relationship between P_1 and P_t. Direct negative relationships between C_p and C_t are apparent at each location in 1967 though not in 1968 at which time the only relationship obtained was with data from Big Bay which exhibited a direct positive relationship. Direct negative relationships between C_p and C_i are evident at Big Bay and Glenora in 1967, and Big Bay and Conway in 1968.

Figure 1 Variations in the aqueous fertility ($g.m^{-3}$) of the trophogenic waters at Big Bay, Glenora and Conway, 1967, 1968, with respect to:

A) particulate phosphorus (P_1) and total phosphorus (P_t)

B) particulate nitrogen (N_1), organic (N_o) and inorganic (N_i) nitrogen

C) particulate carbon (C_p), total inorganic (C_t) and CO_2 (C_i) carbon.

Table I. Average, minimum and maximum values of various parameters for the Bay of Quinte

Parameter	mean	min.	max.	obs.
algae - $cm^3 . m^{-3}$	7.76	0.11	40.72	60
chlorophyll $\underline{a}$ - $mg.m^{-3}$	9.74	1.0	45.2	53
inorganic nitrogen (N_i) $g.m^{-3}$	0.21	0.05	0.45	60
organic nitrogen (N_o) $g.m^{-3}$	0.54	0.06	2.10	60
seston nitrogen N_1 $g.m^{-3}$	0.160	0.040	0.720	60
N_2 $g.m^{-3}$	0.077	0.010	0.250	60
N_3 $g.m^{-3}$	0.051	0.001	0.190	60
total phosphorus (P_t) $g.m^{-3}$	0.046	0.010	0.117	60
seston phosphorus P_1 $g.m^{-3}$	0.0117	0.003	0.032	60
P_2 $g.m^{-3}$	0.0044	0.0005	0.0210	60
P_3 $g.m^{-3}$	0.0029	0.0001	0.0110	60
inorganic carbon (C_t) $g.m^{-3}$	28.58	23.78	32.78	51
CO_2 as C (C_i) $g.m^{-3}$	0.60	0.03	3.97	51
seston carbon C_p $g.m^{-3}$	1.12	0.10	8.40	51

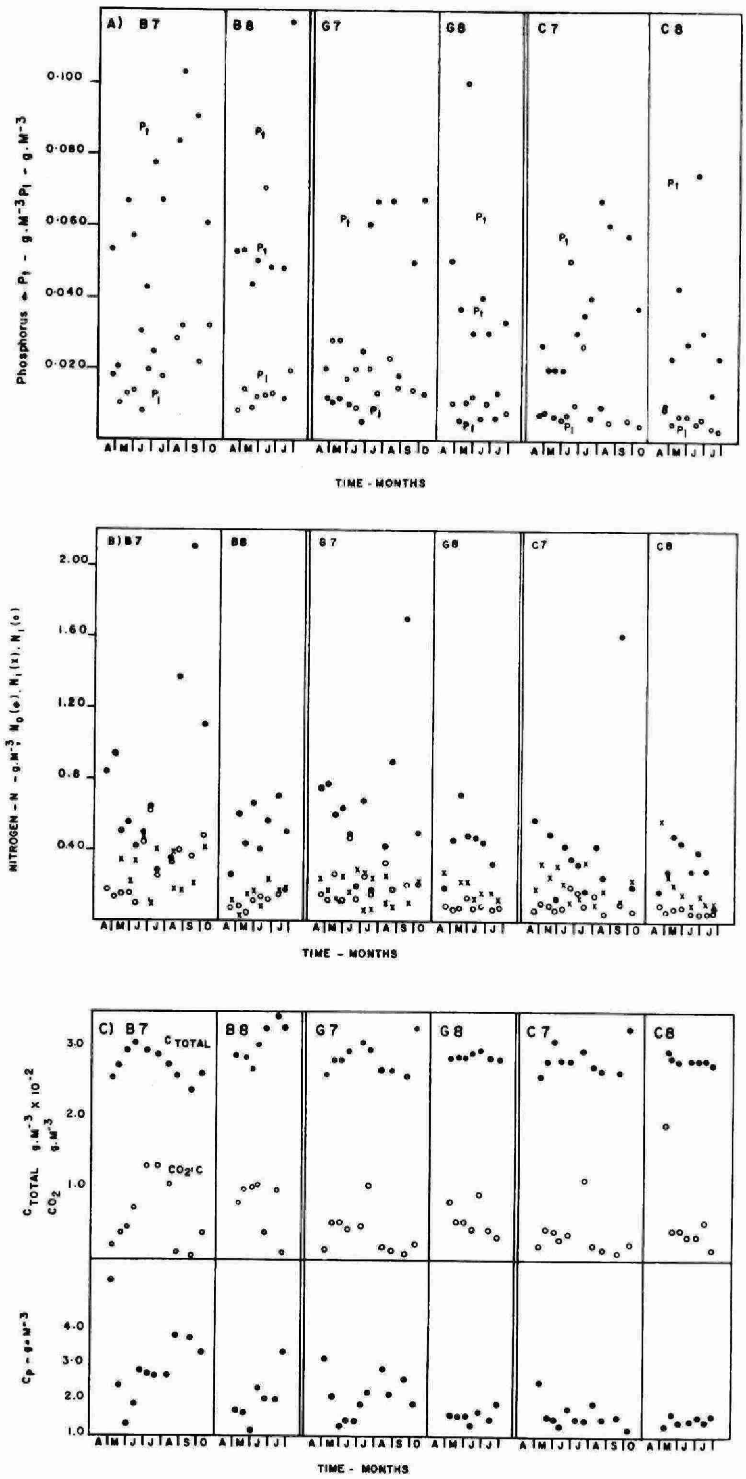


Table II. Relationships between the phosphorus (P_1), nitrogen (N_1), and carbon (C_p) content of the seston ($g.m^{-3}$) and the aqueous fertility ($g.m^{-3}$) - total phosphorus (P_t), inorganic nitrogen (N_i), organic nitrogen (N_o), total inorganic carbon (C_t), estimated CO_2 as carbon (C_i) - in the trophogenic waters at Big Bay, Glenora, and Conway during 1967 and 1968. The regression probability level (P), experimental F value (F exp.), sample standard error ($S\bar{y}.x$) and number of observations (obs.) are indicated.

Regression	P	F exp.	$S\bar{y}.x$	obs.
Big Bay 1967				
$P_1\ (g.m^{-3}) = 0.4321\ (10^2) + 0.2512\ P_t\ (g.m^{-3})$	0.01	11.63	0.1787	12
$N_1\ (g.m^{-3})$ vs $N_o\ (g.m^{-3})$	<0.25	0.56		12
$N_i\ (g.m^{-3})$ vs $N_1\ (g.m^{-3})$	<0.25	0.08		12
$C_p\ (g.m^{-3}) = 0.1309\ (10^2) - 0.4024\ C_t\ (g.m^{-3})$	0.05	10.51	0.2531	10
$C_i\ (g.m^{-3}) = 0.2512\ (10) - 0.3854\ C_p\ (g.m^{-3})$	0.25	1.86	0.1459	10
Glenora 1967				
$P_1\ (g.m^{-3}) = 0.7869\ (10^2) + 0.1327\ P_t\ (g.m^{-3})$	0.05	6.38	0.1130	12
$N_1\ (g.m^{-3})$ vs $N_o\ (g.m^{-3})$	<0.25	0.91		12
$N_i\ (g.m^{-3})$ vs $N_1\ (g.m^{-3})$	<0.25	0.10		12
$C_p\ (g.m^{-3}) = 0.6763\ (10) - 0.1988\ C_t\ (g.m^{-3})$	0.05	5.86	0.1673	10
$C_i\ (g.m^{-3}) = 0.1504\ (10) - 0.1026\ C_p\ (g.m^{-3})$	0.25	1.95	0.0897	10
Conway 1967				
$P_1\ (g.m^{-3})$ vs $P_t\ (g.m^{-3})$	<0.25	0.08		12
$N_1\ (g.m^{-3})$ vs $N_o\ (g.m^{-3})$	<0.25	0.20		12
$N_i\ (g.m^{-3}) = 0.4319 - 0.2364\ (10)\ N_1\ (g.m^{-3})$	0.005	463.74	0.0016	12
$C_p\ (g.m^{-3}) = 0.3725\ (10) - 0.1094\ C_t\ (g.m^{-3})$	0.10	5.18	0.1002	10
$C_i\ (g.m^{-3})$ vs $C_p\ (g.m^{-3})$	<0.25	0.33		10

cont....

Table II (cont)

Regression	P	F exp.	$S\bar{y}.x$	obs.
Big Bay 1968				
P_l $(g.m^{-3})$ vs P_t $(g.m^{-3})$	<0.25	1.36		8
N_l $(g.m^{-3})$ vs N_o $(g.m^{-3})$	<0.25	0.67		8
N_i $(g.m^{-3})$ vs N_l $(g.m^{-3})$	<0.25	0.00		8
C_p $(g.m^{-3})$ = -0.4364 (10) + 0.1776 C_t $(g.m^{-3})$	0.10	4.23	0.2209	7
C_i $(g.m^{-3})$ = 0.1553 (10) - 0.7536 C_p $(g.m^{-3})$	0.10	5.29	0.1112	7
Glenora 1968				
P_l $(g.m^{-3})$ vs P_t $(g.m^{-3})$	<0.25	0.77		8
N_l $(g.m^{-3})$ vs N_o $(g.m^{-3})$	<0.25	0.06		8
N_i $(g.m^{-3})$ = 0.1005 + 0.1120 (10) N_l $(g.m^{-3})$	0.25	1.74	0.0081	8
C_p $(g.m^{-3})$ vs C_t $(g.m^{-3})$	<0.25	0.12		7
C_i $(g.m^{-3})$ vs C_p $(g.m^{-3})$	<0.25	0.16		7
Conway 1968				
P_l $(g.m^{-3})$ vs P_t $(g.m^{-3})$	<0.25	0.04		8
N_l $(g.m^{-3})$ vs N_o $(g.m^{-3})$	<0.25	0.23		8
N_i $(g.m^{-3})$ = -0.1279 + 0.5836 (10) N_l $(g.m^{-3})$	0.10	5.94	0.0053	8
C_p $(g.m^{-3})$ vs C_t $(g.m^{-3})$	<0.25	0.64		7
C_i $(g.m^{-3})$ = 0.4454 (10) - 0.8418 (10) C_p $(g.m^{-3})$	0.05	6.39	0.1306	7

Using the data illustrated in Figure 1, ratios between nitrogen and phosphorus, carbon and phosphorus, and carbon and nitrogen, were calculated for each station each year (Table III).

Seston Nutrient Interrelationships

Interrelationships between the quantities of phosphorus, nitrogen, and carbon present in the seston following the various methods of treatment were investigated.

Regression testing between data representing the amounts of phosphorus or nitrogen present in each fraction were found to yield a positive direct relationship in all cases (Figures 2, 3). Substitution in the appropriate equation of the mean value for each abcissa variable was then carried out to calculate ratios between the various phosphorus or nitrogen parameters. Ratios obtained from these calculations are listed in Table IV.

Assessment of the relative distribution of the seston phosphorus and nitrogen associated with each fraction was carried out by statistical comparison of means. The amounts of phosphorus and nitrogen representing each fraction were found to be significantly different at the $F_{.05}$ level - $P_1 > P_2 > P_3 : N_1 > N_2 > N_3$. Of the mean total phosphorus of the seston (P_1), 37.61 percent exists as P_2 and 24.79 percent as P_3, the latter comprising 65.91 percent of the former. With respect to the average amount of total

Table III. Average nutrient ratios of the seston at each location - nitrogen to phosphorus, carbon to phosphorus, carbon to nitrogen (wt:wt).

	$N_l:P_l$	$C_p:P_l$	$C_p:N_l$
1967			
Big Bay	14.82:1	146.07:1	12.01:1
Glenora	19.39:1	85.81:1	5.84:1
Conway	11.98:1	88.33:1	7.98:1
1968			
Big Bay	8.94:1	83.90:1	9.94:1
Glenora	9.16:1	68.18:1	7.56:1
Conway	10.55:1	93.81:1	8.90:1

Figure 2. Relationships between quantities of phosphorus - P_1, P_2, P_3 - associated with seston samples from the Bay of Quinte.

A) $g\ P_1 = 0.6231(10^{-2}) + 0.1288(10)\ g\ P_2$, P @ 0.005, $S\bar{y}.x = 0.6407(10^{-3})$

B) $g\ P_1 = 0.6347(10^{-2}) + 0.1924(10)\ g\ P_3$, P @ 0.005, $S\bar{y}.x = 0.6494(10^{-3})$

C) $g\ P_2 = 0.5894(10^{-3}) + 0.1317(10)\ g\ P_3$, P @ 0.005, $S\bar{y}.x = 0.2443(10^{-3})$

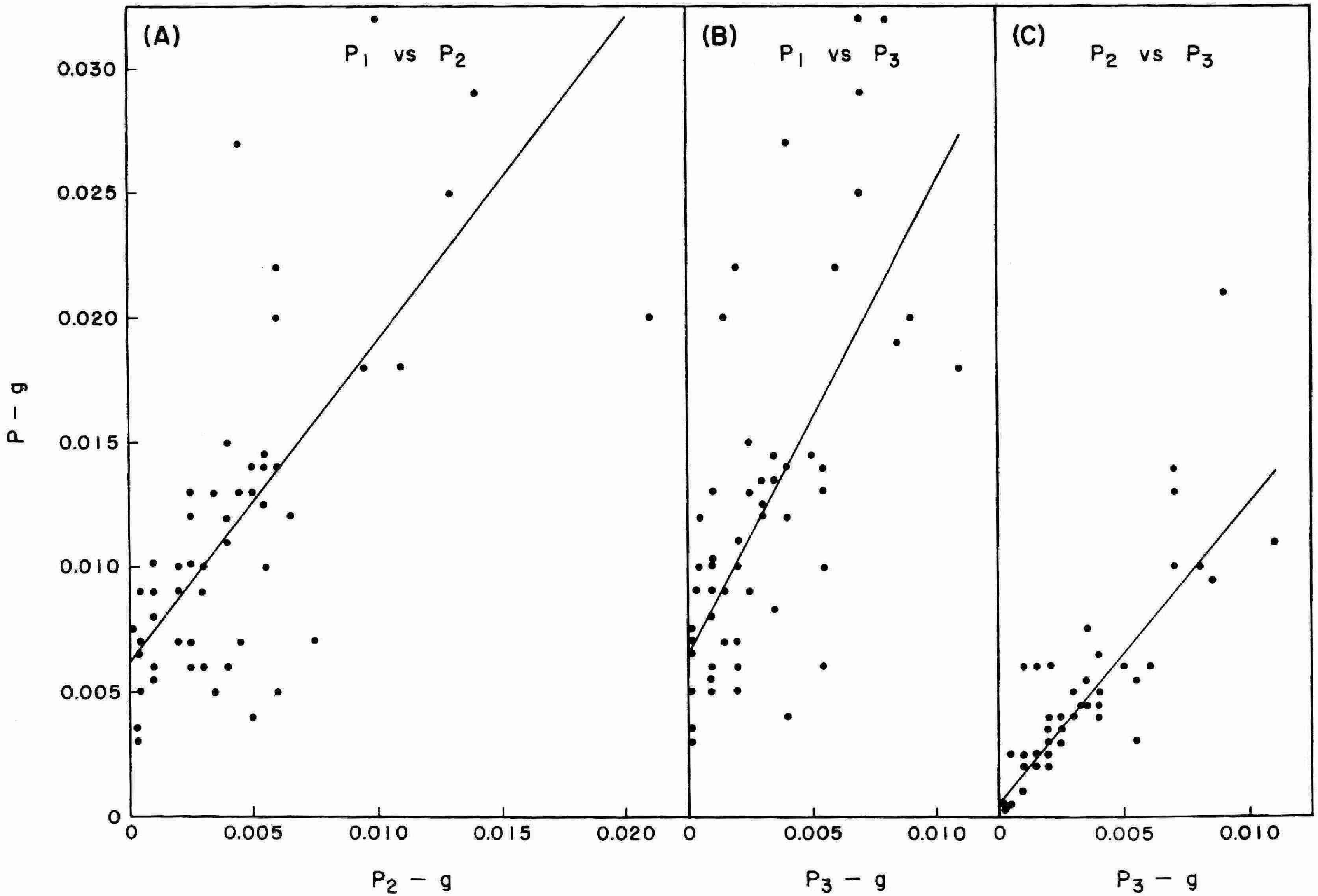
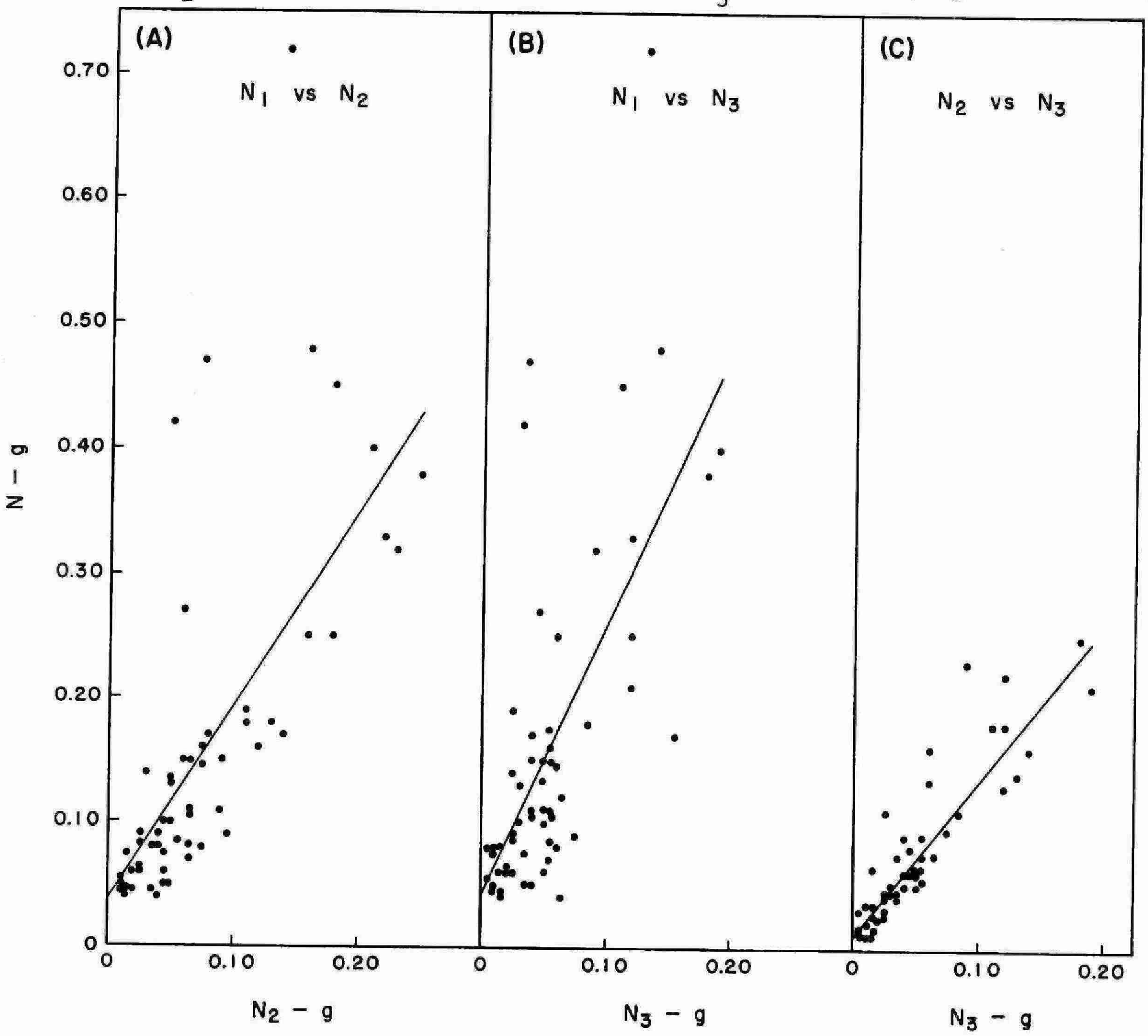


Figure 3. Relationships between quantities of nitrogen - N_1, N_2, N_3 - associated with seston samples from the Bay of Quinte.

A) g N_1 = $0.3759(10^{-1}) + 0.1566(10)$ g N_2, P @ 0.005, $S\bar{y}.x = 0.1307(10^{-1})$

B) g N_2 = $0.4441(10^{-1}) + 0.2170(10)$ g N_3, P @ 0.005, $S\bar{y}.x = 0.1314(10^{-1})$

C) g N_2 = $0.1165(10^{-1}) + 0.1248(10)$ g N_3, P @ 0.005, $S\bar{y}.x = 0.3517(10^{-2})$



nitrogen of the seston (N_1), 48.12 percent is present as N_2 and 31.88 percent as N_3, the latter making up 66.23 percent of the N_2.

Characterization of relationships between the phosphorus and nitrogen data representing each fraction and also the carbon content of the seston were carried out using regression analyses. These data, which are displayed in Figures 4, 5, in all cases indicate a direct positive relationship to exist between the two parameters being tested, although the level of significance of the various regressions does vary. Ratios between the various parameters - N/P, C/P, C/N - were calculated by substitution of the mean value of the abcissa variable in the appropriate equation. Ratios obtained in this manner are listed in Table IV.

Seston Nutrient Content and Phytoplankton Biomass

Data representing the nutrient content of the seston after various treatments and corresponding estimates of the phytoplankton standing crops, expressed as parts per million by volume (cm^3) or chlorophyll a (mg), are graphically illustrated in Figure 6.

Regression testing of these data was found to yield direct positive relationships between the respective parameters in each case, although as was noted previously, some variation in the significance level of the various regressions is apparent.

Figure 4. Interrelationships between the phosphorus and nitrogen (P_1, P_2, P_3, N_1, N_2, N_3) associated with the seston of 60 samples from the Bay of Quinte.

A) $g\ N_1 = -0.1542 + 0.2658(10^2)\ g\ P_1$, P @ 0.005, $S\bar{y}.x = 0.1193(10^{-1})$

B) $g\ N_2 = -0.5584(10^{-1}) + 0.1133(10^2)\ g\ P_1$, P @ 0.005, $S\bar{y}.x = 0.4987(10^{-2})$

C) $g\ N_3 = -0.5024(10^{-2}) + 0.4923(10)\ g\ P_1$, P @ 0.005, $S\bar{y}.x = 0.3500(10^{-2})$

D) $g\ N_1 = 0.5727(10^{-1}) + 0.2364(10^2)\ g\ P_2$, P @ 0.005, $S\bar{y}.x = 0.1366(10^{-1})$

E) $g\ N_2 = 0.2735(10^{-1}) + 0.1168(10^2)\ g\ P_2$, P @ 0.005, $S\bar{y}.x = 0.5370(10^{-2})$

F) $g\ N_3 = 0.1673(10^{-1}) + 0.8402(10)\ g\ P_2$, P @ 0.005, $S\bar{y}.x = 0.3840(10^{-2})$

G) $g\ N_1 = 0.7046(10^{-1}) + 0.3141(10^2)\ g\ P_3$, P @ 0.005, $S\bar{y}.x = 0.1477(10^{-1})$

H) $g\ N_2 = 0.2848(10^{-1}) + 0.1742(10^2)\ g\ P_3$, P @ 0.005, $S\bar{y}.x = 0.5466(10^{-2})$

I) $g\ N_3 = 0.1342(10^{-2}) + 0.1398(10^2)\ g\ P_3$, P @ 0.005, $S\bar{y}.x = 0.3342(10^{-2})$

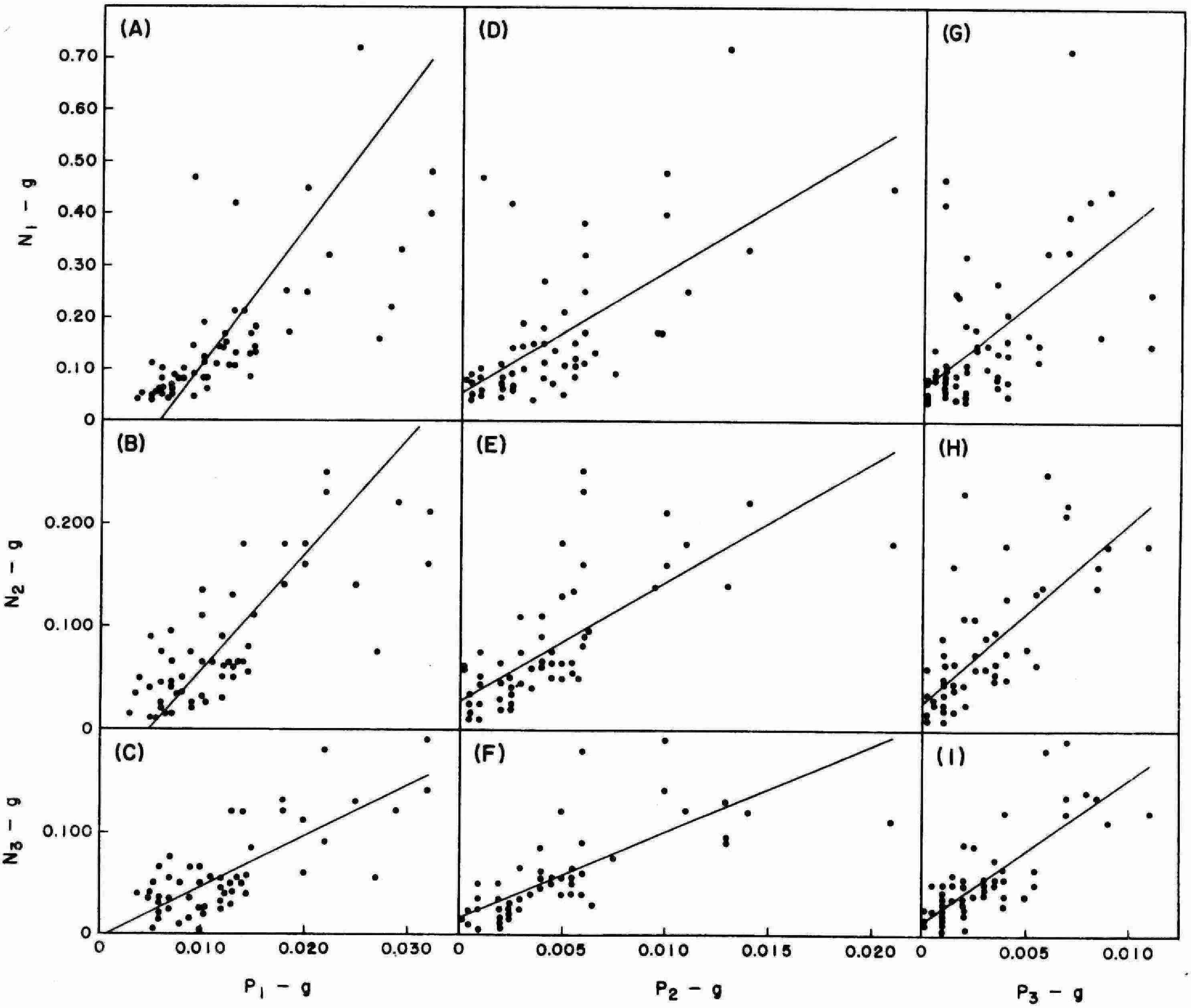


Figure 5. Relationships between the phosphorus (P_1, P_2, P_3) or nitrogen (N_1, N_2, N_3) and organic carbon (C_p) associated with the seston of 60 samples from the Bay of Quinte.

A) $g\ C_p = 0.1971 + 0.7855(10^2)\ g\ P_1$, P @ 0.005, $S\bar{y}.x = 0.1456$

B) $g\ C_p = 0.5122 + 0.1415(10^3)\ g\ P_2$, P @ 0.005, $S\bar{y}.x = 0.1460$

C) $g\ C_p = 0.3148 + 0.2852(10^3)\ g\ P_2$, P @ 0.005, $S\bar{y}.x = 0.1324$

D) $g\ C_p = 0.6731 + 0.2828(10)\ g\ N_1$, P @ 0.05, $S\bar{y}.x = 0.1538$

E) $g\ C_p = 0.3116 + 0.1043(10^2)\ g\ N_2$, P @ 0.005, $S\bar{y}.x = 0.1395$

F) $g\ C_p = 0.2565 + 0.1635(10^2)\ g\ N_3$, P @ 0.005, $S\bar{y}.x = 0.1329$

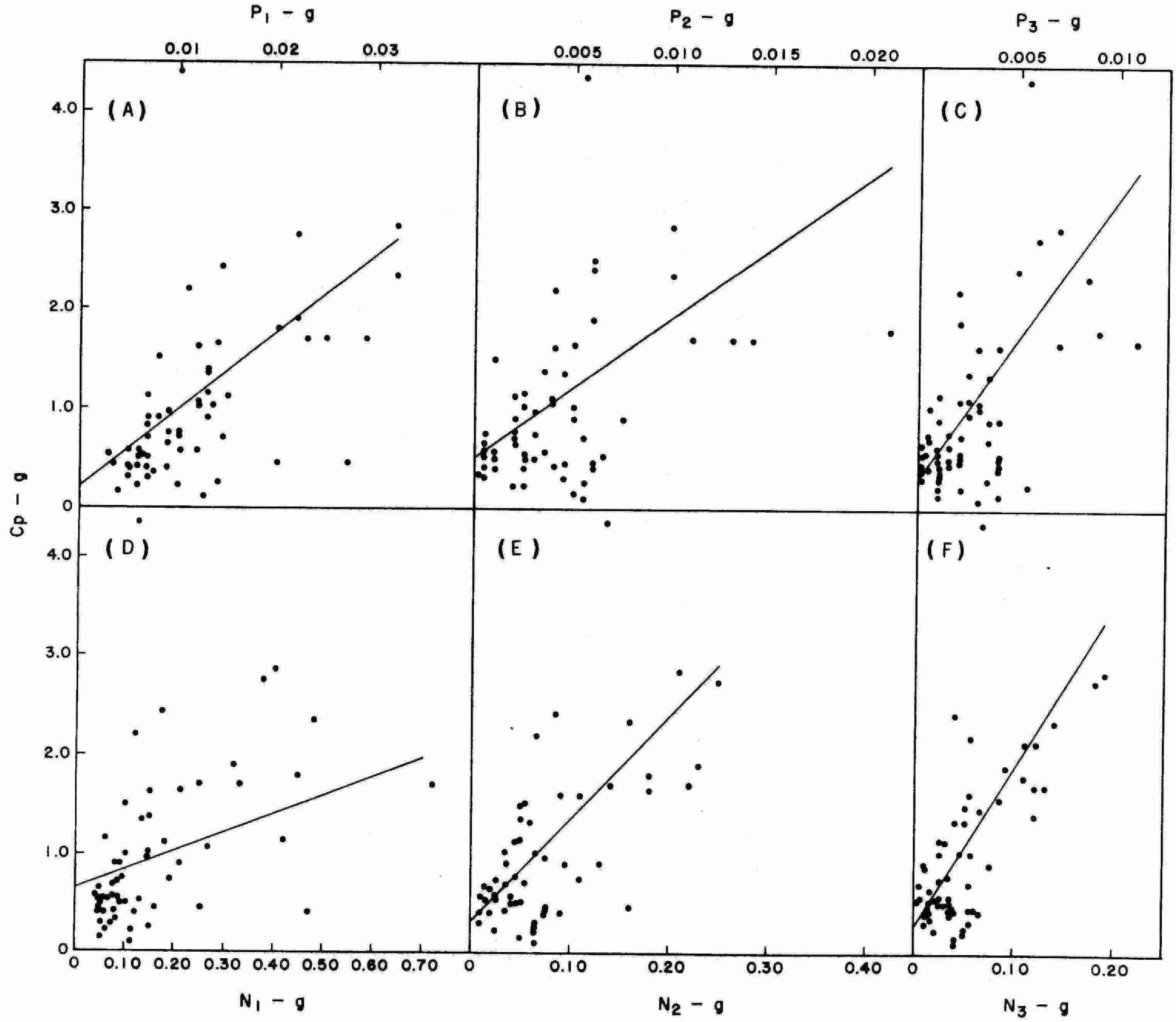


Table IV. Various seston nutrient ratios as derived from the regression equations of Figures 2, 3, 4, 5 (wt:wt).

$P_1:P_2$	2.66:1	$N_1:N_2$	2.08:1
$P_1:P_3$	4.04:1	$N_1:N_3$	3.14:1
$P_2:P_3$	1.52:1	$N_2:N_3$	1.31:1

$N_1:P_1$	13.68:1	$N_2:P_1$	6.58:1	$N_3:P_1$	4.36:1
$N_1:P_2$	36.36:1	$N_2:P_2$	17.50:1	$N_3:P_2$	11.59:1
$N_1:P_3$	55.17:1	$N_2:P_3$	26.55:1	$N_3:P_3$	17.59:1

$C_p:P_1$	95.73:1	$C_p:N_1$	7.00:1
$C_p:P_2$	254.54:1	$C_p:N_2$	14.54:1
$C_p:P_3$	386.21:1	$C_p:N_3$	21.96:1

Figure 6. Comparisons between the phosphorus (P_1, P_2, P_3), nitrogen (N_1, N_2, N_3) and carbon (C_p) of the seston and standing crops of algae (cm^3) (60 samples) or chlorophyll a (mgXP) (53 samples).

A) $g\ P_1 = 0.8229(10^{-2}) + 0.4620(10^{-3})\ cm^3$, P @ 0.005, $S\bar{y}.x = 0.7065(10^{-3})$

B) $g\ P_2 = 0.2831(10^{-2}) + 0.1933(10^{-3})\ cm^3$, P @ 0.005, $S\bar{y}.x = 0.4351(10^{-3})$

C) $g\ P_3 = 0.1850(10^{-2}) + 0.1277(10^{-3})\ cm^3$, P @ 0.005, $S\bar{y}.x = 0.2874(10^{-3})$

D) $g\ N_1 = 0.8212(10^{-1}) + 0.1001(10^{-1})\ cm^3$, P @ 0.005, $S\bar{y}.x = 0.1321(10^{-1})$

E) $g\ N_2 = 0.4719(10^{-1}) + 0.3967(10^{-2})\ cm^3$, P @ 0.005, $S\bar{y}.x = 0.6232(10^{-2})$

F) $g\ N_3 = 0.2806(10^{-1}) + 0.3233(10^{-2})\ cm^3$, P @ 0.005, $S\bar{y}.x = 0.4059(10^{-2})$

G) $g\ C_p = 0.8392 + 0.3684(10^{-1})\ cm^3$, P @ 0.05, $S\bar{y}.x = 0.1556$

H) $g\ P_1 = 0.7204(10^{-2}) + 0.5038(10^{-3})$ mgXP, P @ 0.005, $S\bar{y}.x = 0.7144(10^{-3})$

I) $g\ P_2 = 0.2729(10^{-2}) + 0.1763(10^{-3})$ mgXP, P @ 0.005, $S\bar{y}.x = 0.4624(10^{-3})$

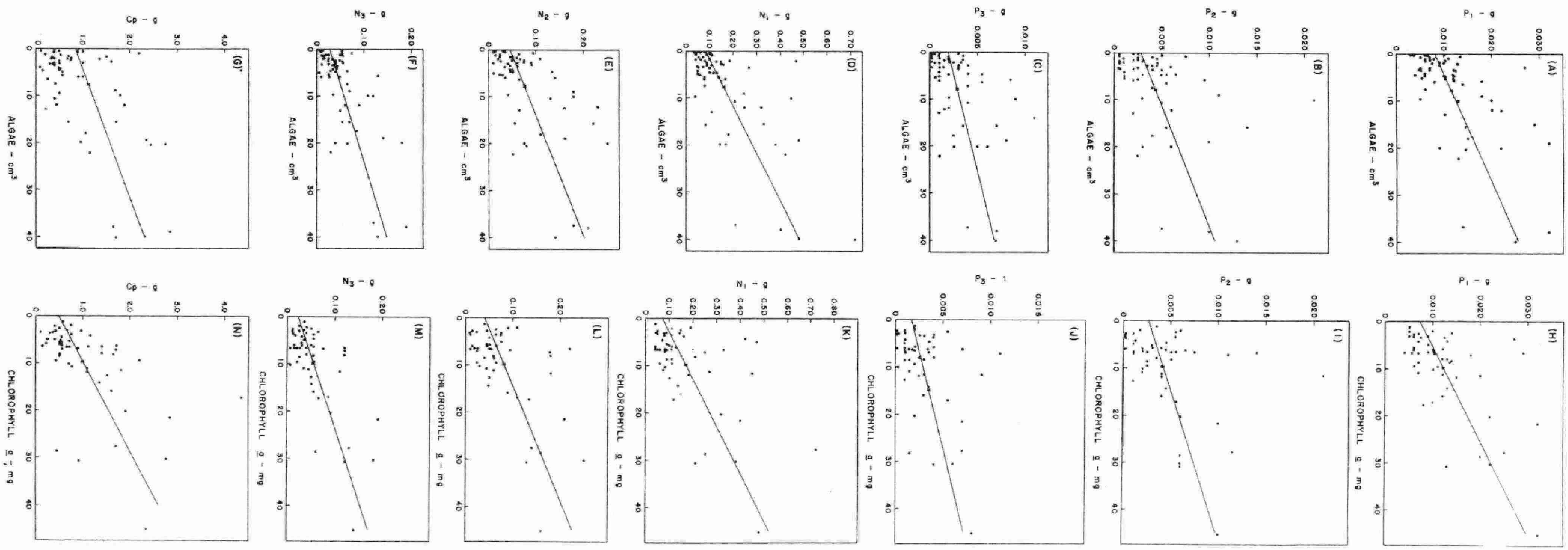
J) $g\ P_3 = 0.1710(10^{-2}) + 0.1221(10^{-3})$ mgXP, P @ 0.005, $S\bar{y}.x = 0.2844(10^{-3})$

K) $g\ N_1 = 0.7294(10^{-1}) + 0.9630(10^{-2})$ mgXP, P @ 0.005, $S\bar{y}.x = 0.1514(10^{-1})$

L) $g\ N_2 = 0.4097(10^{-1}) + 0.4138(10^{-2})$ mgXP, P @ 0.005, $S\bar{y}.x = 0.6495(10^{-2})$

M) $g\ N_3 = 0.2389(10^{-1}) + 0.3243(10^{-2})$ mgXP, P @ 0.005, $S\bar{y}.x = 0.4198(10^{-2})$

N) $g\ C_p = 0.4928 + 0.5246(10^{-1})$ mgXP, P @ 0.005, $S\bar{y}.x = 0.8729(10^{-1})$



Nutrient biomass ratios, listed in Table V, were calculated by substituting the mean value of the abcissa parameter in the appropriate equation.

DISCUSSION AND CONCLUSION

Nutrient ratios of algae and the seston of field samples - N:P, C:P, C:N (weight:weight) - have been employed to indicate the relative availability of phosphorus and nitrogen for phytoplankton growth. Nitrogen to phosphorus ratios typically are of the order of 10 - 15:1, but have been found to range from 1:1 to 60:1, the former suggesting a low nitrogen, high phosphorus availability, and the latter the reverse. Carbon to phosphorus and carbon to nitrogen ratios have been observed to lie between 18 - 90:1 and 5 - 25:1 respectively (Strickland, 1960; Hutchinson, 1967; Vollenweider, 1969; Mackenthum, 1965). Estimation of standing crops of algae, based on the phosphorus, nitrogen and carbon content of the seston have been suggested. As plants have the ability to accumulate phosphorus and perhaps nitrogen in excess of their immediate requirements, "luxury uptake", estimates of algal quantities by this means may not be too reliable.

Average nutrient ratios of the seston at each sampling location in 1967 and 1968 have been calculated (Table III) and for the most part lie within the ranges

Table V. Ratios between the nutrients of the seston and standing crops of algae (cm^3) and chlorophyll a, as derived from the regression equations of Figure 6.

g $P_1:cm^3$	0.0015:1	g P_1:mg Chlor. a	0.0012:1
g $P_2:cm^3$	0.0006:1	g P_2:mg Chlor. a	0.0004:1
g $P_3:cm^3$	0.0004:1	g P_3:mg Chlor. a	0.0003:1
g $N_1:cm^3$	0.0206:1	g N_1:mg Chlor. a	0.0172:1
g $N_2:cm^3$	0.0099:1	g N_2:mg Chlor. a	0.0084:1
g $N_3:cm^3$	0.0066:1	g N_3:mg Chlor. a	0.0058:1
g $C_p:cm^3$	0.144:1	g C_p:mg Chlor. a	0.103:1

outlined above except at Big Bay 1967 in the case of carbon to phosphorus - 146:1. Nitrogen to phosphorus ratios of the seston at Big Bay, 1967 and Conway 1967, 1968, suggest a more or less balanced supply of both nutrients. The ratio at Glenora, 1967 implies a somewhat limiting supply of phosphorus, with the reverse being the case at Big Bay and Glenora, 1968.

From the results of various regression analyses with the above data (Table II) seston phosphorus (P_l) was found directly related to total phosphorus (P_t) only at Big Bay and Glenora, 1967. At no location was any relationship obtained between seston nitrogen (N_l) and the total organic nitrogen content (N_o) of water samples. A negative direct relationship between inorganic nitrogen (N_i) and seston nitrogen (N_l) exists at Conway, 1967, though not elsewhere and in fact these two parameters displayed a positive direct relationship at Glenora and Conway, 1968.

Support for the interpretation of phosphorus and nitrogen availability based on average ratios (Table III) is indicated in some instances from the regression analyses such as between seston and total phosphorus (P_l and P_t) at Big Bay and Glenora, 1967 (Table II). On the other hand the N:P ratio at Conway, 1967 would not suggest a limiting relationship with respect to nitrogen availability as implied from the regression. The absence of either a direct

positive relationship between P_1 and P_t or a direct negative relationship between N_i and N_1 suggests a balanced supply of these nutrients at the remaining stations - Big Bay, Glenora, Conway, 1968 or that responses are related to some factor not measured in this study.

The organic carbon associated with the seston (C_p) at each station has also been found in most cases to illustrate a direct negative relationship when compared to concentrations of either total inorganic carbon (C_t) or estimated CO_2:carbon dioxide as carbon (C_i) present in the water at all locations except Glenora, 1968. At Big Bay, 1968 for some reason the relationship between C_p and C_t is of a positive linear nature.

Statistical comparison of means of quantities of phosphorus associated with the seston after various treatments indicates $P_1 > P_2 > P_3$ (wt:wt). The seston phosphorus fraction P_3 is considered to approximate the essential phosphorus requirement of the biomass as described by Fitzgerald and Nelson (1966) for algae. The phosphorus associated with the different fractions were found to be all directly related (Figure 2) and ratios calculated from these regressions - $P_1:P_3$ - 4.1:1, $P_2:P_3$ - 1.5:1 (Table IV), are in approximately the same order of magnitude as found by (Borchardt and Azad,1968, Azad and Borchardt, 1970) between luxury and essential phosphorus with cultures of algae - 3:1.

Taking the same approach with the nitrogen data of each fraction it has been shown that $N_1 > N_2 > N_3$ (wt:wt) and that direct relationships exist between increases in these quantities (Figure 3). The ratios $N_1:N_3$ of 3.1:1 and $N_1:N_3$ of 1.3:1 might also be indicative of some form of luxury accumulation of nitrogen in the seston (Table IV).

Further comparisons between the phosphorus, nitrogen and carbon quantities of the seston indicate the existence of positive linear relationships in all cases (Figure 4). Such comparisons suggest a close inter-relationship between these parameters, as represented by the different fractions, with respect to the accumulation of more labile to the most tightly bound portions of the P_3 and N_3 moieties. Whether or not similar fractionation of the organic carbon may have occurred following the different treatments of the seston was not examined.

If the quantities associated with the P_3 and N_3 fractions represent the essential phosphorus and nitrogen requirements of the algae, then the optimum ratio between these two nutrients as indicated by the $N_3:P_3$ ratio is 18:1 (Table IV), a ratio also obtained between N_2 and P_2. The remaining ratios could then represent those situations associated with varying availabilities of phosphorus and nitrogen: $N_1:P_3$ - 55:1, $N_1:P_2$ - 36:1, $N_2:P_3$ - 26:1 - a high nitrogen and low phosphorus; $N_3:P_1$ - 4:1, $N_2:P_1$ - 6:1, $N_3:P_2$ - 12:1 a low nitrogen and high phosphorus. The carbon

to nitrogen ratios $C:N_1$ - 7.1:1, $C:N_2$ - 14:1 and $C:N_3$ - 22:1, are likewise within the range typically encountered, 5 - 25:1. Except for the carbon to phosphorus ratio $C:P_1$ - 96:1 which is at the upper range of published ratios, the $C_p:P_2$ and $C_p:P_3$ ratios illustrate relationships not previously reported.

When data representing the phosphorus, nitrogen and carbon quantities of the seston were compared to associated standing crops of phytoplankton (cm^3), or chlorophyll a (mg), a direct positive relationship was obtained in each instance (Figure 5). Nutrient:biomass ratios were then calculated from the appropriate regression equations. Christie (1972) has previously suggested that the amount of phosphorus required per unit cell volume, based on a maximum observed ratio between cm^3 and total phosphorus concentrations in the Bay of Quinte was 0.00096 g P per cm^3. This value is less than that obtained between P_1 and cm^3 - 0.0015 $g:cm^3$ but in excess of P_2 and cm^3 - 0.0006 $g:cm^3$ and $P_3:cm^3$ - 0.0004 $g:cm^3$. This latter ratio, however, does correspond quite closely to the minimum value of phosphorus required per unit cell volume which has been rated for several species of algae - 0.0002 - 0.0006 g $P:cm^3$, as calculated by Vollenweider (1970) from the works of several authors.

The maximum quantity of algae associated with a minimum concentration of organic nitrogen yielded a ratio of 0.0071 mg $N:cm^3$ (Christie, 1972). This ratio is less than

that obtained between N_1 and cm^3 - 0.0206 $g:cm^3$ and N_2 and cm^3 - 0.0099 $g:cm^3$ and lies very close to that obtained between N_3 and cm^3 - 0.0066 $g:cm^3$.

Phosphorus to chlorophyll a and nitrogen to chlorophyll a ratios of 0.00075 g P:mg chlorophyll a and 0.007 g N:mg chlorophyll a have been suggested as being applicable to most populations of algae (Strickland, 1960). Ratios obtained in this study between P_1, P_2, and P_3 and chlorophyll a (g:mg), of 0.0012:1, 0.0004:1 and 0.0003:1 respectively, range from almost double to somewhat less than one half of the above. In the case of nitrogen to chlorophyll a, observed ratios between N_1, N_2, and N_3 and chlorophyll a (g:mg) are 0.017:1, 0.008:1 and 0.006:1. The former is more than double the suggested ratio; the latter two values, however, are quite close, one slightly above and the other slightly below.

Mullin et al (1966) in examining the relationships between carbon content and cell volume found that the ratio can range from less than 3 percent up to 25 percent by weight per unit cell volume, the lower percentage being associated with large species and the higher value with smaller species of algae. With the type of diverse population which constitutes the seston of samples of this study no similar appraisal is possible. The ratio $C_p:cm^3$ obtained here of 0.14 g $C:cm^3$ although higher than that suggested by Vollenweider (1969) - 10 percent by weight per cm^3 - does lie within the 0.09 - 0.15 g $C:cm^3$ range of

Cushing (1957) and is very close to the 0.13 gm $C:cm^3$ obtained by Cushing and Nicholson (1957) with the alga Skeletonema.

Certainly the seston of samples examined in this study do not consist entirely of phytoplankton and therefore may overestimate the essential phosphorus and nitrogen requirements of algae alone, but on the other hand perhaps yield a more realistic appraisal with respect to natural community composition and competition. The suggested breakpoint between a eutrophic and highly eutrophic environ, on the basis of phytoplankton density is 10 $cm^3.m^{-3}$ (Vollenweider, 1970). The amount of phosphorus and nitrogen required to support this quantity of phytoplankton in a natural community is, from the $P_3:cm^3$ and $N_3:cm^3$ ratios (Table V), in the order of 0.0004 g $P:m^{-3}$ and 0.0066 g $N:m^{-3}$. If on the other hand, one assumes that the accumulation of nitrogen and phosphorus by algae in excess of immediate requirements is a more realistic assessment of in vivo phytoplankton growth relationships, the quantities of the two nutrients potentially required for the formation of algal blooms are - as derived from the $P_1:cm^3$ and $N_1:cm^3$ ratios - 0.0015 g $P:cm^3$ and 0.021 g $N:cm^3$ which are greater than values obtained from actual field observations as noted above (Christie, 1972).

The absence of excessive developments of algae when available phosphorus and nitrogen exceed these levels, would suggest that phytoplankton responses are being suppressed by the interaction of other factors of a biological, chemical or physical nature.

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